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Sensing device

Field of the invention

This invention relates to a sensing device for acquiring data related to conditions in a wellbore and characteristics of formations surrounding the wellbore.

Background to the invention

Measurement of characteristics, such as fluid conductivity and temperature, are often required along the length of a wellbore or borehole so as to collect depth-indexed information on surrounding rock and fluid formations or the state of the wellbore. One way of acquiring depth-indexed data relating to such characteristics is to lower a sensing device, or measuring tool, downhole on a wireline. By retracting the wireline, the tool can acquire data along the length of the borehole during the upwards journey.

Other ways of measuring such characteristics are to permanently distribute sensors along the length of the well at fixed locations. This allows monitoring of data over time and depth. Alternatively data can be acquired solely over time by the use of measuring tools located at a fixed position at the bottom of a drill-string.

The present invention aims to provide an alternative way of acquiring data downhole.

Summary of the invention

According to one aspect of the present invention, there is provided a sensing device for acquiring data in a fluid-containing system, such as a wellbore, comprising a body associated with an acquisition means to acquire and store data relating to conditions within the fluid-containing system, wherein the body is adapted to be transported by fluid flow. The sensing device can thus be used to acquire and store data relating to conditions such as pH, ion concentrations, temperature and fluid conductivity downhole in association with pressure or depth measurements, and to store and convey the acquired data to surface during travel through fluid within the wellbore. Data which is both time-indexed and pressure-, or depth-, indexed can thus be acquired.

The sensing device may be adapted to be transported by fluid convection, typically within a borehole, so avoiding the need for the device to have a self-contained motive power source.

The body may substantially surround and contain the acquisition means so as to protect the acquisition means from vigorous conditions, such as those experienced downhole.

Preferably the body further comprises a releasable connection which allows the body to be secured in the

fluid-containing system ready for release to begin data acquisition.

The body may be provided with a fluid inlet to allow samples of fluid to be collected by the acquisition means during travel of the body to surface. This allows sampling of the borehole fluids over depth.

The acquisition means may comprise a sensor means capable of acquiring and storing data relating to conditions within the fluid-containing system and a detection means, such as a pressure sensor, to detect the pressure at which data is acquired. For a wellbore, typically the detection means is a pressure sensor, with the pressure detected providing a measure of the depth in the wellbore. In this way, data obtained downhole can be indexed to the depth at which the data is acquired.

The acquisition means may further comprise data storage means and data processing means to allow for analysis of the acquired data by the sensing device.

The sensing device is typically placed downhole during completion of a well, preferably by attaching it to part of a completion drill string with the releasable connector which releases the device from the string in response to signals from surface passed downhole along the completion drill string.

The invention also lies in the provision of a plurality of sensing devices as aforesaid downhole, the devices

being placed within a protective container secured downhole and the container comprising an actuable port to release the sensing devices. Thus the devices may be released singly from the container, or in multiples so as to replicate measurements.

Thus in accordance with another aspect of the present invention, there is provided a method of acquiring time-indexed and depth-indexed data, the method comprising securing a sensing device in a fluid-containing system by use of a tethering means, actuating the tethering means so as to release the sensing device for travel through fluid, acquiring data relating to at least one characteristic associated with the fluid-containing system as the sensing device travels through the fluid, and storing the acquired data within the sensing device for retrieval.

Thus data relating to borehole conditions can be acquired remote from any surface connection.

The invention also comprises use of the sensing device as aforesaid when downhole.

Brief Description of the Drawings

The invention will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 shows a schematic diagram of a sensing device according to the present invention when in position downhole;

Figure 2 shows a schematic diagram of the sensing device;

Figure 3 shows a schematic diagram of one method of placing a plurality of sensing devices downhole;

Figure 4 shows a block diagram of electronic circuitry and controllers associated with the sensing device; and

Figure 5 shows a data and control flow diagram for use in association with the sensing device.

Description

Detailed Description of the Invention

Figure 1 shows a wellbore 10 drilled from surface 12 through a rock formation 14. The wellbore 10 has been completed by insertion of a completion string 16 to which a sensing device 20 is attached by a tether 22. The sensing device 20 is in communication with processing equipment 24 at surface via wireline 26.

The sensing device 20, or sensule, is shown in detail in Figure 2 and comprises a hollow rigid body 30, typically made from a lightweight metal such as aluminium, containing a power source 32, such as a chemical battery with a power output of 50mAh, an array of sensors and transducers 34, an electronic processor, or integrated

circuit device, 36 and a sampling port 40 which provides exposure of at least one of the sensors 34 to the fluid within the borehole 10.

The device 20 is a small self-contained robust unit, typically 0.01m in diameter although it can be as small as 3mm, and includes a means of depth-indexing the acquired data, which is generally a pressure sensor 42. The electronic processor 36 typically includes time-base and memory elements, and generally comprises signal conditioning, signal processing and data storage elements. Thus the device 20 provides a very small, integrated, self-powered sensor system where integrated sensor systems on substrates, such as silicon, can be provided to detect and record acceleration, pressure, chemical analysis and many other characteristics.

The sensors 34, 42 within the body 30 measure properties such as fluid temperature, fluid conductivity, total salinity, gases such as methane, hydrogen sulphide and carbon dioxide, and various fluid chemical composition parameters such as pH, ion concentrations etc. In addition fluid can be sampled, so that small samples of borehole fluid can be collected at particular depths or in a depth-indexed way.

Once the sensule 20 is positioned downhole, the sensule 20 is released from the tether 22 to acquire data relating to the wellbore. The sensules can be released on receipt of a command sent from the processing equipment 24 via the wireline 26, known as active

release, or at pre-determined or pre-programmed time intervals. The sensing device 20 is carried by fluid convection from the high pressure region at the tether 22 to the low pressure region at surface 12 so as to travel up the wellbore to surface. As the sensing device 20 travels from the point of release to surface, the sensors 34, 42 produce data relating to the characteristics along the length of wellbore 10 and the time-series and depth-indexed data is stored by the processor 36.

The sensule 20 thus makes measurements throughout the well, reducing calibration and offset errors which are experienced in a string of sensors at fixed stations. The sensule 20 can be adapted to calibrate sensors permanently positioned downhole by communicating with them via a short-range electromagnetic communication system as the sensule 20 travels to surface 12.

Alternatively instead of being convected to surface, the power source 32 can be used to drive the device 20 through the fluid, for example where it is desired to acquire data over a certain depth for a shorter time than travel by convection permits.

Once at the surface, the sensule 20 is recovered by mechanical filtering of the production fluid and data stored in the electronic processor 36 is then downloaded via download connection 38 into the processing equipment 24 for analysis and manipulation.

By using a sensule which is conveyed slowly to surface whilst acquiring data, data acquisition is well adapted to the slow time-rate of change of the conditions in the producing well for which only very low frequency data is required.

With the pressure sensor 42, the sensule 20 is capable of acquiring data of high depth resolution, closely approaching that of a true distributed measurement.

Instead of providing one sensing device for release downhole, a plurality of sensing devices can be provided by securing a container or nest 44 downhole, the nest containing a large number of sensing devices. The nest 44 can be placed at the bottom of the well during the initial well construction so that it is below the production zone. However slim elongate nests, carried by wire-line or coiled tubing, may be positioned downhole during the producing life of a well when data is required on specific producing problems, such as water production occurring in particular intervals.

Such a nest 44 is shown in Figure 3 and is a canister permanently attached to the completion string 16 with the individual sensing devices 20 released from the nest 44 when a command via wireline 26 instructs the nest 44 to release one or more sensing devices via port 46. The sensules may need activating before release. The connection of the nest to surface via wireline 26 allows successive sensing devices 20 to be released at discrete intervals in time for return to surface.

Instead of an electromechanical release of the sensules from the port 46, other means are possible such as embedding the sensules in a slowly dissolving matrix, which then frees individual sensules for release from the nest 44 as the matrix dissolves.

The use of a nest 44 to encapsulate the sensing devices 20 before release ensures that the sensing devices 20 are protected from the extreme conditions downhole for almost all of their lifetime in the well. This substantially reduces contamination and performance deterioration which besets permanent downhole sensors over many years of installation.

A variety of different types of sensing devices can be placed in the nest. For example, some devices may be adapted to sense and record fluid temperature, fluid and electrical conductivity and pressure (i.e. depth), with others adapted to sense and record ion concentrations such as for ions of sodium, calcium, barium and chloride, and pressure. Varying release patterns of the sensing devices from the nest 44 can be used to provide optimal statistical sampling, and release rates from the nest programmed from the surface and varied to provide answers to particular operational questions. Each sensing device 20 can be recalibrates or reprogrammed immediately before release if required.

Where a nest 44 is used, arrival of a defective sensing device at surface can trigger the release of a

replacement device, so avoiding undue delay in acquiring data. Also a number, or shoal, of devices can be released simultaneously to replicate measurements and to improve data reliability.

In Figure 4, a block diagram schematically illustrates the different processing elements within a sensule 60 and the external elements required on surface to retrieve data from the sensule 60. Typically the various processing elements incorporated into the sensule are integrated into a silicon CMOS device. This allows the power required for the sensule to be reduced, so permitting use of a smaller battery, and also reduces the size of the sensule body needed to contain the processing elements and other components.

The sensule 60 has four sensors 62, 64, 66 and 68 which respectively sense chemical features such as ions, conductivity in the surrounding fluid, pressure (i.e. depth) and temperature. Any practical number, or type, of sensors may be incorporated into the sensule 60 depending on the application for which the sensule is required. Each sensor is connected to a microcontroller 70 via an appropriate data modification circuit or device. Thus temperature sensor 68 passes acquired data to a linear output circuit 72 which then passes the modified data to the integrated microcontroller 70. Similarly pressure sensor 60, such as a silicon diaphragm, passes data to a differential amplifier 74 before transmission to the microcontroller 70. Conductivity sensor 64 passes data to the microcontroller

70 via a detection circuit 76, with chemical sensor 62 passing data via current measurement device 80.

The microcontroller 70 comprises a multiplexer 82 connected to an analogue-to-digital convertor (ADC) 84 which is in turn connected to a controller 86. The ADC 84 is in two-way communication with the controller 86. Only one-way communication is necessary from multiplexer 82 to the ADC as the multiplexer is only required to receive data from the sensors and the associated data modification circuits or devices. The controller 86 has two set of input and output ports which are respectively connected to EEPROM 90 and an infra-red (ir) transceiver 92.

External to the sensule 60, at surface, there are provided an ir transceiver 94 in two-way communication with PCMCIA controller 96, and a portable computer 100 in two-way communication with the PCMCIA controller 96. The ir transceiver 92 within the sensule 60 is able to transmit and receive data to/from the ir transceiver 94, so enabling download of data from the sensule to the computer 100 and also remote control of the controller via commands from the computer 100.

Whilst reference is made to ir transceivers, any type of remote signalling may be used to allow the sensule to communicate with processing equipment on surface, such as radio frequency (RF) communication.

When taking measurements, the operational lifetime of a sensule can be extended by adopting a "standby" mode between each measurement so that power is conserved.

Figure 5 shows how data flow and control can be achieved for the sensule.

Various examples of how the invention can be used are now described.

Example 1: Chemical monitoring during production of produced water compositions as a function of depth.

A sensule nest is built into the well during construction. This contains several thousand sensules, of several different types which are colour-coded (for example, red, blue, green, black and white) for ease of identification. Red sensules measure borehole pH and carbonate as a function of time and depth; blue sensules measure chloride ion, sulphate ion and barium ion; green sensules measure hydrogen sulphide. Black sensules detect specific scale inhibitor chemicals. White sensules capture fluid samples of 0.1mL volume at 100m intervals during the passage to surface. Second generation sensules may be multicoloured, providing several or all of these functions in one unit. The colour coding of the sensules ensures that on retrieval of the sensules from the fluid, sensules acquiring the same or related data can easily be selected for data analysis at the same time.

The nest is closed from contact with borehole fluids, but incorporates an actuable port for ejecting sensules one by one into the fluid, according to a preprogrammed schedule, which may be reprogrammed from surface. Before release, each sensule is checked and calibrated automatically by electronics built into the nest at the ejector port. Sensules of each colour are released at 10 day intervals.

At surface, all sensules are detected automatically, shunted from the flow line and interrogated to download an identification tag, pressure and temperature. Chemical concentration data are read directly from the red, green and blue sensules. The black and white sensules enter an automatic chemical microanalysis system which carries out detailed quantitative assays of inhibitor chemical and fluid composition. Data from the white sensule is used to cross check data from the red, green and blue sensules.

Sensule data form a comprehensive time-series record of the chemical composition variation during the producing life of the well. Such data are of value in designing chemical treatments for inorganic scale control; for monitoring and treating reservoir souring; for detecting water breakthrough; and for assessing conformance control interventions.

Example 2: Detection of tracer breakthrough into producing well.

A nest is provided at the bottom of the well and contains sensules for measuring tracer species. Lithium salts are injected into the fluid reservoir associated with the well in a tracer test. The sensules are released at a high rate (5/h) over a 20 day period (2400 total) to determine the lithium ion profile in the well at high spatial and temporal resolution. A full breakthrough history is acquired as a function of depth.

Example 3: Analysis of hydrocarbon composition with depth.

A nest is provided at the bottom of the well and contains sensules for acquiring hydrocarbon mini-samples. The sensules are intercepted automatically at surface and passed to an at-line chromatography/mass spectrometer for complete composition analysis, from which PVT properties are computed directly. Risk factors for waxing, asphaltene and gas hydrate are flagged automatically. Molecular biomarker analysis is used to improve deep reservoir mapping.

Example 4: Analysis of fluorescence of chemiluminescence in produced hydrocarbon.

The sensules are configured to detect fluorescence signatures as a function of depth to identify precise horizons in producing intervals.

Example 5: Analysis of inert gases with depth.

Sensules are used to detect or capture inert gases in produced fluid and record this as a function of depth. The acquired data are used to determine reservoir connectivity.

Example 6: Microbiological sampling.

Sensules are released which detect or capture micro-organisms entering the well at different depths. Such data contribute new information for reservoir delineation and the treatment of reservoir souring.

Example 7: Production logging.

Temperature records are valuable in determining water entry and other changes in flow patterns through the reservoir and into the well. Regular sensule releases, such as weekly allow trends to be monitored much more closely than by typical production logging which usually only monitors once a year, and thus use of sensules allows more timely well interventions.

Whilst the above examples refer to applications using the sensules in wells, it will be apparent to the person skilled in the art that sensules are also applicable for use in other technologies as general process monitoring devices, such as in process plants for chemical manufacture, drug manufacture and food processing.